Statistical Analysis of Synthetic Aperture Radar (SAR) Image Speckle

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Statistical Analysis of Synthetic Aperture Radar (SAR) Image Speckle

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By

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Declaration

I hereby declare that

1) The work presented in this paper is original and has been done by myself under the guidance of my supervisor.
2) The work has not been submitted to any other Institute for any degree or diploma.
3) The data used in this work is taken from only free sources and its credit has been cited in references.
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5) I have followed the thesis guidelines provided by the Institute.

Manvender Singh Rathore

2nd may 2014

Department of Electronics & Communication Engineering

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CERTIFICATE

This is to certify that the Thesis Report entitled "Statistical Analysis of Synthetic Aperture Radar (SAR) Image Speckle" submitted by MANVENDER SINGH RATHORE bearing roll no. 212EC6194 in partial fulfilment of the requirements for the award of Master of Technology in Electronics and Communication Engineering with specialization in "Signal and Image Processing" during session 2012-2014 at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Abstract

Synthetic aperture radar (SAR) is an active imaging system that can achieve high resolutions both in range and azimuth. This system has found many real time applications in diverse fields such as geophysics, hydrology, archeology etc. The idea behind SAR is to synthesize the effect of large aperture by moving small aperture radar along the flight path to obtain much finer resolution. While moving along the flight path, the SAR system records reflected waves from the imaged surface at different instants. Coherent processing of these reflected waves from illuminated area of different range and azimuth results in the formation of 2-D SAR images. However, such recorded SAR raw data contains unwanted artifacts which result in granular appearances in SAR image. Those granular parts in SAR image is known as speckle which is multiplicative in nature. Presence of such speckle noise degrade the SAR image quality significantly leading to loss of crucial information. To remove these unwanted signal, statistical properties of speckle needs to be analyzed. So, statistical modeling of the speckle in SAR data plays a key role in the context of SAR image processing and applications.

In this research work, we use compound model to separate out the speckle and texture content of recorded SAR raw data. Texture preserving filters such as Lee, Frost, Kuan filter are used to extract texture, and this texture is further used to separate out speckle. Using the estimate of parameters involved in statistical distribution of speckle, the characteristic function method, the approximation of Edgeworth expansion method, and the Method of moments approaches are considered for obtaining the probability density function (pdf) of speckle part of real SAR data obtained from Sandia National laboratory. To validate the usefulness of the above methods for analyzing speckle, we examine the goodness-of-fit between histogram obtained from real SAR data and the pdfs estimated using the above techniques.

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List of Abbreviations

SAR	- Synthetic Aperture Radar
CG	- Compound Gaussian
KL-Distance	- Kullback Leibler distance
MOM	- Method of Moments
IGCG	- Inverse Gaussian Compound Gaussian
MMSE	- Minimum Mean Square Error
LLMMSE	- Local Linear Minimum Mean Square Error
NMNV	- Non-stationary Mean Non-stationary Variance
Pdf	- Probability Density Function
EM	- Electromagnetic
GPS	- Global Positioning System

CHAPTER-1

Introduction

1.1 Introduction:

Synthetic Aperture Radar (SAR) is widely in use for remote sensing and other geological reearches. Synthetic Aperture Radar offers good resolution over radar by using movement of antenna with respect to the object without of any post processing. It could fit on a satellite or on the side of a plane because of smaller aperture, or antenna length. First measured SAR image was formed in 1953, when c-46 airborne was used to map a section of west, Florida, and after that National Aeronautics and Space Administration (NASA) developed the first on-board satellite SAR in 1978. Russia(1987), Europe(1991), and Canada(1995) also launched their own satellite carrying SAR system [1]-[3].

Initially SAR was primarily used only for vigilance application to detect opponents' territories, aero-planes, tanks but afterword some other applications also came in existence like geophysics, oceanography, archeology etc.

1.2 Applications of SAR

There are many applications [1] of SAR in different areas like in

1. Geology: In geology, SAR imagery system mainly used to know potential of floods, level of earthquakes, and volcano eruption.
2. Ecology: hazard monitoring, forest classification, oil spilling, environmental study, and in detection of squatters.
3. Hydrology: In hydrology SAR is mainly used to check moisture in soil, and snow water equivalence.

4. Oceanography: In oceanography is mainly used to see ocean currents, ocean surface features, winds, thickness of ice in sea, and in other coastal activities.
5. Agriculture: SAR is very much important in agriculture field to monitor crops in a large area very easily.
6. Archeology: To take images of old buildings
7. Mining: to monitor mines

1.3 Basic SAR Imaging Principle:

Synthetic aperture radar is a kind of imaging radar similar to a conventional radar mounted on a moving platform, in which sequentially transmitted electromagnetic (EM) waves backscattered from surface and again received at radar antenna in the form of echo. In SAR consecutive transmission and reception with appropriate coherent combination make a virtual aperture which is larger than actual antenna length [1]-[2].

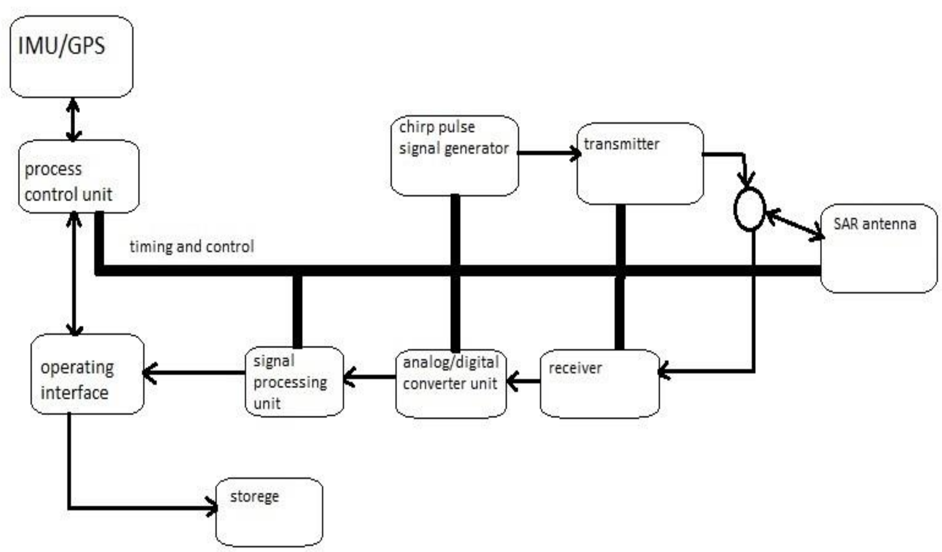


Figure 1. 1-basic block diagram of SAR system

SAR system block diagram is shown in fig. in this system timing and control signals are generated by processor control unit. Stepped frequency or liner frequency modulated pulse generated by chirp pulse signal generator and passed to transmitter. SAR system have a single antenna for transmission and reception [5]. The transmitted SAR signal reflected back from the object or scene, reflected signal collected at the SAR antenna and this passed to receiver, than signal passed to analog/digital converter unit from receiver to get sampled and digitized signal. This digital signal passed through signal processing unit, where raw SAR image constructed which contains errors occurred by moving platform and other atmospheric effects. Range migration and range walk effect also affect SAR image. SAR system contains global positioning system (GPS) and inertial measurement unit (IMU) sensors to record history of flight. This raw image processed again to extract information.

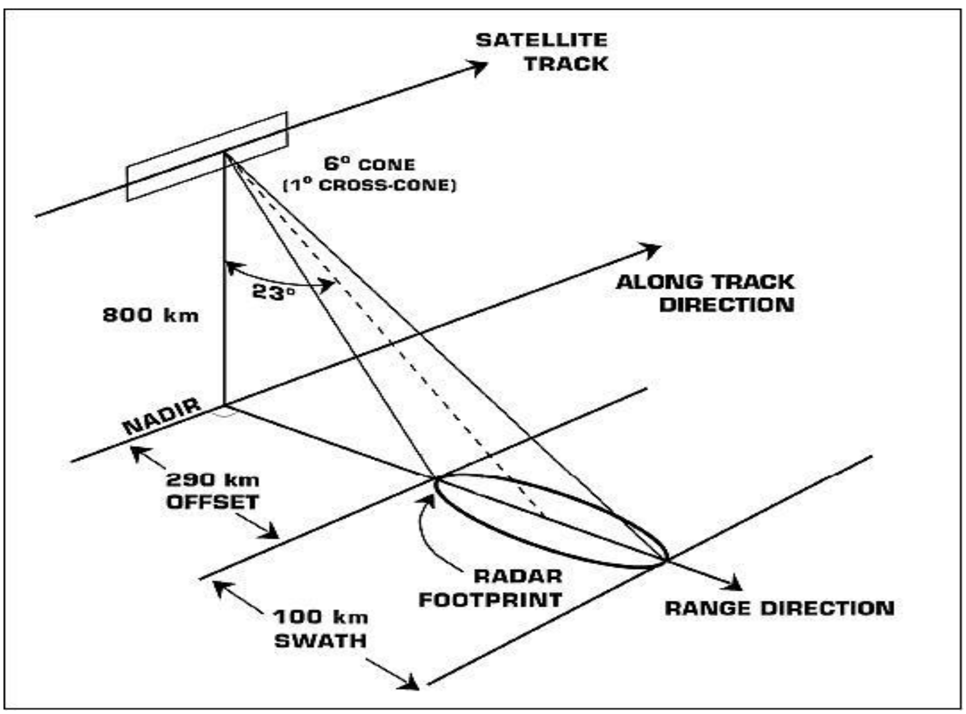


Figure 1. 2 - SAR imaging geometry

1.4 SAR mode of operations:

According to the scanning operation of radar antenna, mode of operation of SAR can be divided into three modes.

1.4.1 Side-looking SAR or strip-map SAR:

This mode of operation is used to observe a strip of a surface parallel to the airborne path, in this radar collects the electromagnetic waves reflected from the region alongside which it travels [1].

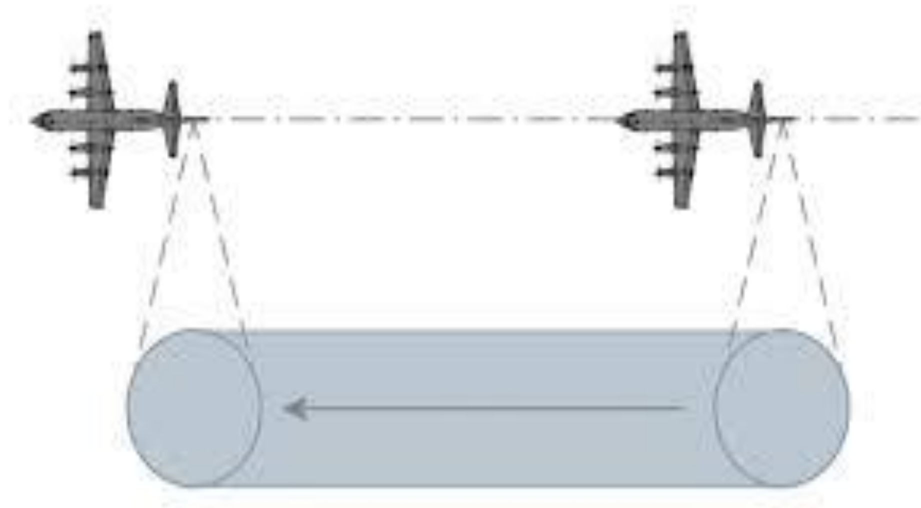


Figure 1. 3 -side-looking SAR or strip-map SAR

1.4.2 Spotlight SAR:

In this SAR mode of operation radar focuses and tracks to a fixed point, this mode is basically used for surveillance and to take multi-look images of the target [1].

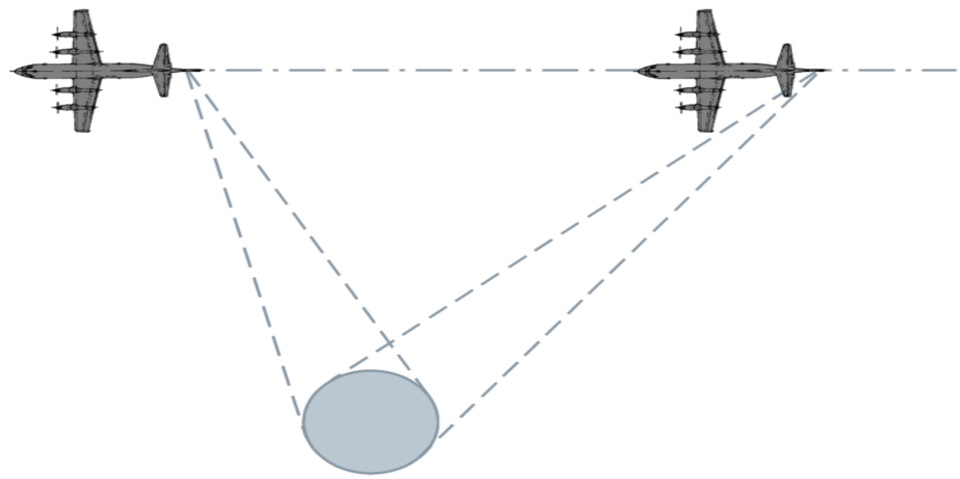


Figure 1. 4 - spotlight mode of SAR

1.4.3 Scan SAR:

This mode is used when radar is at high altitude and observe a wider area. For this mode observation area divided into several segments. As the airborne moves, radar illuminate one segment for a while and then moves to illuminate another segment. Google map is a typical example of scan SAR mode [1].

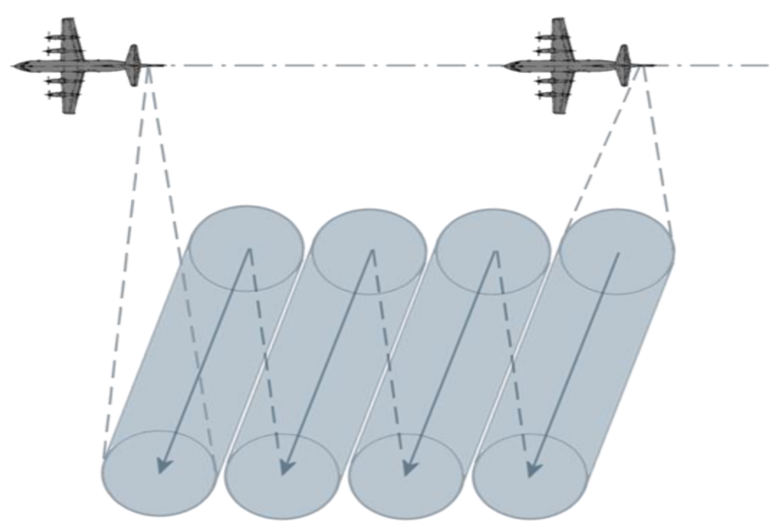


Figure 1. 5 - scan SAR

1.5 Problems observed in SAR imaging:

To process raw SAR image some problems are observed, out of them few are easily recoverable but few are very difficult to overcome, these problems are briefly discussed here.

1.5.1 Range migration:

Range distance of any scattered object follows a parabolic curve which called as range curvature, when it is illuminated by the radar wave an ambiguity in range distance may observed in cells after shifting of scatters to the nearest range cells [1]. During integration of raw SAR data over synthetic aperture time interval this phenomenon of ambiguity is called as range migration [1]-[2].

In case of space-borne SAR integration time and range extent is always more than airborne SAR, so curvature can be significant, and for airborne SAR antenna's footprint on the ground is much shorter. Therefore, range resolution of scatterer may be greater than range delay, and this cause no range migration.

Another phenomenon called range walk may cause range migration. If integration time is long, the revolution of earth makes shifting of the position of target (scatterer) with respect to the SAR. This problem may occur when ground object is moving. These problems may cause range migration in image cells. To correct this range migration problem Doppler frequency domain procedure is required.

If the range error calculated by both of these effects is δR.

Total range can be written as $R + \delta R$

$$R+\delta R = \left(R^2 + \left(\frac{v_y . T_s}{2} \right)^2 \right)^{\frac{1}{2}} \qquad (1.1)$$

Here we have, $T_s = \frac{R.\Omega}{v_y}$,

using this we can calculate value of δR in form of R and **Ω**

$$\delta R = R.\frac{\Omega^2}{8} \qquad (1.2)$$

with Δr = range resolution

$$N = \frac{\delta R}{\Delta r} = R.\frac{\Omega^2}{8\Delta r} \qquad (1.3)$$

If N is more than 1, range migration correction is required, if not then no correction is needed.

1.5.2 Motion errors in SAR imaging:

The basic theory of SAR based on the assumption of stationary object or target. If an object in scene is moving Doppler shift posed by the object's line of sight velocity take the wrong distance information about the position of the object to the phase of the received electromagnetic waves [2]. When moving speed of object is so fast, it occupies the several pixels of image during the integration interval of SAR. So the image of object blurred like fog in sky.

This phenomenon will not occur when speed of object is slow, but the location of object will still be wrong because of Doppler shift. To decrease these type of motion errors some motion compensation techniques are available in literature.

1.5.3 Speckle noise problem in SAR:

SAR resolution cells have a most varying size, start from few centimeters to tens of meters, depending on bandwidth of frequency and size of the synthetic aperture. Electromagnetic wave diffracted from such uneven surface will have various phase values, net effect on image pixel can be constructive or destructive [7]. Noise like behavior shown by this phenomenon is known as ground clutter or speckle noise [6]. There are few techniques available in literature to reduce speckle noise like by using multi-look image processing, and statistical filtering. Statistical filters are available in literature are lee filter, kaun filter, frost filter etc.

In this project we consider only speckle noise problem to reduce speckle noise from SAR images by using statistical filtering. Motion error and range migration errors can be remove by perfect SAR imagery set up.

1.6 Motivation:

SAR imagery is mainly used for geology, ecology, hydrology, oceanology, archeology, agriculture, mine detection, remote sensing, automatic target detection (ATR). Major problem in SAR imagery is that the texture is affected by multiplicative type of speckle noise. To extract maximum information from recorded 2-D SAR image we need to extract the texture, and need to remove speckle noise [13].

1.7 Objective:

To remove speckle from recorded SAR data first we need to estimate speckle parameters to examine its' distribution characteristic. For this we use modeling of SAR data set to separate out speckle and texture, and estimation techniques to estimate speckle parameters [15]. To obtain pdf of speckle we use these estimated parameter and pdf generation methods

1.8 Layout of the Thesis:

This thesis is organized into five chapters. The first chapter deals with the introduction of SAR. Chapter 2 contains literature review related to this project. Chapter 3 deals with speckle separation techniques and pdf estimation techniques of speckle. Chapter 4 contains data description used in project and experimental results. Chapter 5 deals with conclusion and scope for the future.

CHAPTER-2

Literature Review

2.1 Literature review

SAR is widely in use because of their high resolution remote sensing and useful information for mapping, surface surveillance, search-and-rescue, mine detection, and automatic target recognition (ATR). To access maximum information noise removal is necessary in SAR images, that's why many researchers are working in this area of noise estimation and removal techniques.

In a way of studying speckle analysis of SAR images many research papers found on speckle extraction from raw SAR data, texture extraction, statistical properties of SAR images, and statistical properties of speckle. In this process of literature review we get to know what type of distributions speckle do follows in different-different condition of imaging. Literature review is as given below.

1. Alin Achim and, Panagiotis Tsakalides, "Shrinkage Based on Heavy-Tailed Modeling," IEEE Transactions on Geoscience and Remote Sensing, vol. 41, no. 8, 2003

   Annotation: In this paper noise filtering technique is shown which reduces speckle in SAR images while preserving the textural information structural features and structural features of the scene. Initially author shown the sub-band decompositions of log transformed SAR images can be accurately modeled by alpha-stable distributions [4], a family of heavy-tailed densities**,** and then used the alpha-stable model to develop a blind speckle-suppression processor that performs a nonlinear operation on the data and then related this nonlinearity to the degree of non-gaussianity of the sample data.

Analysis: For $\alpha < 2$ speckle shows non-gaussianity and follow a kind of heavy- tailed distribution, and global compromise between smoothing and edge preservation achieved by the proposed filter.

2. Hua Xie, Leland E. Pierce, and Fawwaz T. Ulaby, "Statistical Properties of Logarithmically Transformed Speckle," IEEE Transactions on Geoscience and Remote Sensing, vol. 40, no. 3, 2002

   Annotation: To convert the multiplicative speckle model to an additive noise model the logarithmic transform is often employed in SAR image processing. Statistics of SAR images totally changed by this nonlinear operation [6].

   The magnitude of speckle field follows Rayleigh distribution. In this paper author has given two different methods to find pdf of magnitude and log transformed magnitude of speckle for multiplicative model, first one is characteristic function method and, other one is approximation method using the Edgeworth Expansion, and at last this pdf compared with Gaussian approximation.

   Analysis: Characteristic function method is much more time complex then compared to edgeworth expansion method. It has been established that, as the number of looks increases, the pdf of a speckle random variable approaches the Gaussian pdf. One issue related to the logarithmic transformation arises from the fact that the mean of the log-transformed speckle noise is not zero, whereas a significant set of techniques assume Gaussian white noise with zero mean.

3. J.S. Lee, "Digital image enhancement and noise filtering by use of local statistics," IEEE Trans. Pattern Analysis and Machine Intelligence, vol. PAMI-2, no. 2, pp. 165–168, 1980.

Annotation: In this paper, author has given a noise filtering technique which is based on the variance and local mean in a two-dimensional image. The algorithm given in this shares the characteristics in that each pixel is processed independently. Before filtering, the a priori variance and mean of each pixel is derived from its local variance and mean. Then the minimum mean-square error (MMSE) estimator is used to obtain the noise filtering algorithm [8].

Analysis: Lee filter suppress the speckle noise efficiently but there are some drawbacks that it over smooth the information in the image.

4. D.T. Kuan, A.A. Sawchuk, T.C. Strand, and P. Chavel, "Adaptive noise smoothing filter for images with signal-dependent noise," IEEE Trans. Pattern Analysis and Machine Intelligence, vol. PAMI-7, no. 2, pp. 165–177, 1985.

Annotation: In this paper, author has introduced an adaptive noise smoothing filter based on a non-stationary mean, non-stationary variance (NMNV) image model. The non-stationary mean describes the gross structure of an image and the non-stationary variance characterizes edge and elementary texture information of the image. Then a local linear minimum mean square error (LLMMSE) filter is derived based on the NMNV image model [9]. So the adaptive noise smoothing filter is able to change characteristics according to the local image statistics and to different types of signal-dependent noise.

Analysis: This filter is an extension of the Lee filter. The difference between them is that the Kuan filter regards the multiplicative noise as a signal-dependent additive noise. The drawback of it is, like Lee filter, over smoothing of edges and textures.

5. V.S. Frost, J.A. Stiles, KS Shanmugan, and J.C. Holtzman, “A model for radar images and its application to adaptive digital filtering of multiplicative noise,” IEEE Trans. Pattern Analysis and Machine Intelligence, vol. PAMI-4, no. 2, pp. 157–166, 1982.

Annotation: Algorithm given in this paper develops a model of a SAR image, which portrays the observed radar image as corrupted by multiplicative-convolved noise. Then this model is used to propose a minimum mean square error (MMSE) filter to estimate the terrain backscatter from the image data. The design of this MMSE filter is based on the assumption of stationarity of both the signal and the noise [10], but the image is non-stationary on a global basis. Analysis of the model shows that only the local observed mean and standard deviation are required to properly adapt the filter.

Analysis: frost filter is an example based on MMSE criterion. It is an adaptive filter to the local structure in the image according to the local mean and local variance. It is developed based on the previously proposed SAR image model, a multiplicative-convolution model. The drawback is the same as that of Lee and Kuan filter, i.e. blurring the details.

6. Zhenghao Shi and KO B. Fung, “A Comparison of Digital Speckle Filters”

Annotation: There are Some of the well-known adaptive speckle reduction filters like lee filter, kaun filter, frost filter, enhanced lee and enhanced frost filter. These all filters are compared and evaluated based on practical criteria and objective. The performance of the filters is tested by using acquired SAR images.

Analysis: In this classical paper author used several practical criteria and objective to evaluate some of the well-known adaptive speckle reduction filters is done. As is known, the desired feature of a speckle filter is to smooth out speckles while preserving the useful information [11]. However, the experimental result indicate that there is always a kind of tradeoff between these two requirements. In addition, the performance of the results usually affected by parameters of the filters.

7. Milindkumar V. Sarode, Prashant R. Deshmukh, "Reduction of Speckle Noise and Image Enhancement of Images Using Filtering Technique" IJICT

Annotation: This paper proposed filtering techniques for the removal of speckle noise from the SAR images. Quantitative measures in experiment done by using signal to noise ratio (SNR) and standard deviation is used to measure the noise level.

Analysis: The performance analysis of the algorithm has been done using visual performance measures. Performance of the Speckle noise reduction model and level for Synthetic Aperture Radar imagery is well as compared to other filters like lee, kaun, visu, bayes [8]. Histogram results shown much closed equivalency in between original SAR images and de-noised SAR i.e. enhanced images.

8. Maria S. Greco, and Fulvio Gini, "Statistical Analysis of High-Resolution SAR Ground Clutter Data" IEEE Transactions on Geoscience and Remote Sensing, vol. 45, no. 3,2007

Annotation: This classical paper deals with the problem of modeling high resolution synthetic aperture radar (SAR) clutter data from different-different areas. Various known statistical models tested on real data of grass field or wood and trees to validate the goodness of fit of the compound Gaussian model in different scenarios.

Analysis: The results demonstrate that for grass fields, the compound Gaussian model provides a good data fitting [9], and in the case for woods images where the speckle is not more Gaussian distributed.

CHAPTER-3

Statistical Analysis of Speckle

3.1 Statistical modeling of SAR data

This research work is based on speckle analysis of SAR images, basically SAR raw data is in complex form because of the constructive and destructive interference phenomenon of scattered electromagnetic wave from the object surface. This raw complex data is also called as ground clutter. This raw data have some amplitude and some intensity, absolute value of complex data is called amplitude, and intensity contains phase part also [17].

For this we do parametric modeling of raw data, this further can be divided into three types

1. Empirical model
2. Scattering model
3. Compound model

Empirical model based on observation of variables of distribution or experience. It doesn't based on theoretical approach. In this we assume mathematical model of data and compare it with any distribution, if data follow same distribution then we estimate clutter with pdf of that distribution, and if it is different then we try any other distribution. Empirical model is used for clutter data only, not for speckle and texture individually [1].

Scattering model of SAR imagery based on physics of backscatter from object in high frequency. This scattering model is basically used for automatic target recognition. The model characterizes both frequency and aspect dependence of scattering center. In high resolution of SAR image pixel distance and size of pixel is very less [1].

Both empirical and scattering model is used for clutter amplitude data, but in this research work we are working on estimation of speckle and texture, so for that we go with compound model of SAR.

Compound model is also called multiplicative model, researchers have proved that speckle noise always exist in multiplicative form. Compound model of SAR data is in multiplicative form of speckle and texture [15] as

$$y(t) = \sqrt{\tau(t)}.|x(t)| \tag{3.1}$$

Where τ is texture part, and x is speckle part of SAR, and t = (m,n) is pixel location in two dimension SAR image.

The texture takes into account the local power variation of the radar backscattering in the image, texture is the very less amplitude variation area in the image, whereas speckle known as instant amplitude variation area in image. In case of SAR each pixel of raw image is product of texture and speckle noise. Complex envelop of speckle can be modeled as

$$x(t) = x_I(t) + jx_Q(t) \tag{3.2}$$

$x_I(t)$ is in-phase component and $x_Q(t)$ is quadrature component of speckle [15]. For homogeneous scenes, both in-phase and quadrature are usually modeled as two joint Gaussian spatially stationary process with zero mean and variance $\mathrm{var}\{x_I(t)\} = \mathrm{var}\{x_Q(t)\} = 1/2$, so that $E\{|x(t)|^2\} = 1$

Texture can be calculated as

$$\hat{\tau}(m,n) = \frac{1}{L^2} \sum_{j=m}^{m+L-1} \sum_{k=n}^{n+L-1} r^2(j,k) \tag{3.3}$$

Where m = 1,2,……M-L+1 and n = 1,2,……..N-L+1

To calculate speckle from this estimated texture needed a division operation to each pixel of raw data set by square-root of texture.

Estimated speckle is

$$|\hat{x}(m,n)| = y(m,n) / \sqrt{\hat{\tau}(m,n)} \tag{3.4}$$

There are many types of compound models available for SAR images. One kind of compound model is Gaussian compound model, in which speckle follows Gaussian distribution and one of its parameter follow another distribution like K distribution in which one of the parameter of speckle follows Gamma distribution.

If parameter of speckle follow inverse Gaussian then compound model is called as IG-CG. If parameter of speckle follow inverse Gamma then compound model is called as InvGamma-CG.

Another type of compound model is Weibull compound model, in which speckle follows weibull distribution and parameter of speckle follows gamma distribution.

3.2 Extraction of texture:

To estimate speckle from SAR image first we need to extract texture from the raw data. To extract texture we uses some texture filters which are already present in literature like mean filter, lee filter, Kuan filter, frost filter, enhanced lee filer, and enhanced frost filter. Out of these only mean filter is non-adaptive filter and other are adaptive filters [19-[21]], because in mean filter pixel value (weight) of window is one for the whole image. It doesn’t change pixel value like other adaptive filter [22].

3.2.1 Mean filter:

In mean filter we use a window of the order of odd value with same weight of one, order of window is always lesser than size of image. According to window size we append zeros in all four sides of image, and then multiply window to the image matrix, then we take mean of that multiplication and replace the middle value of window by this mean [19]. Then we shift window to the next location of image.

$$f(m,n) = \frac{1}{M.N} \sum_{\{s,t\} \in S_{m,n}} g(s,t) \tag{3.5}$$

$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

Figure 3.1- window for mean filter

3.2.2 Lee filter:

When the minimum mean square error (MMSE) criterion applied to the liner multiplicative model of $I(t) = R(t).u(t)$ the speckle reduction filter formed [8],[11].

Where t = (x,y) , and R(t) denote the surface reflectivity and u(t) is a multiplicative speckle noise, which is statistically independent of R(t). Estimated R(t) from I(t) is given as

$$\hat{R}(t) = I(t).W(t) + \bar{I}(t).(1 - W(t)) \tag{3.6}$$

Where W(t) is the function for weight of window

$$W(t) = 1 - \frac{C_u^2}{C_i^2(t)} \tag{3.7}$$

here we can see that W(t) depends on t, so it called as adaptive filter, and

$$C_u = \frac{\sigma_u}{\bar{u}} \;,\; C_i(t) = \frac{\sigma_i(t)}{\bar{I}(t)} \tag{3.8}$$

3.2.2 Kuan filter:

This filter is given by Kuan et al. In this the multiplicative model first transformed to an additive model [9]-[11]. After applying MMSE criterion we get speckle filter, it is very similar to lee filter, only window weight changed very little. This is also called as extended version of lee filter.

$$W(t) = \frac{1 - \dfrac{C_u^2}{C_i^2(t)}}{1 - C_u^2} \tag{3.9}$$

3.2.3 Frost filter:

Previously in case of lee filter and kuan filter we multiply image with the new impulse response but in case of frost filter we do convolution of image data matrix and the impulse response we get. The impulse response for this process get by MMSE between observed image and scene reflectivity model [10]-[11]. This process is considered as autoregressive process.

Impulse response is

$$m(t) = e^{KC_I^2(t_0).|t|} \tag{3.10}$$

Where K is the controlling constant to control the damping of the impulse, t_0 is the pixel which to be filtered. Value $C_I(t_0)$ is divided in two parts, first is for small $C_I(t_0)$ in this condition filter works as low pass (smoothing) filter and for large value of $C_I(t_0)$ it gives the original image back, similar filter to the lee and kuan filter [29]-[30].

3.3 Estimation of speckle:

To estimate statistical properties of speckle and logarithmic speckle we compare pdf of speckle with Rayleigh distribution by using two different techniques given by Hua Xie, Leland E. Pierce, and Fawwaz T. Ulaby. First technique is characteristic function method and other one is approximation of edgeworth expansion technique, both of the techniques are available for multi-look SAR images

3.3.1 The Characteristic Function Method

$$\phi(t) = \int_0^\infty \frac{\pi x}{2} \exp(-\frac{\pi x^2}{4}) \exp(jxt) df \tag{3.10}$$

Here $\phi(t)$ is the characteristic function of Rayleigh distributed speckle x, and now pdf of x_L for no. of looks L=1, using this characteristic function

$$p_{xL}(x_L) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \phi^L(\frac{t}{L}) \exp(-jx_L t) dt \tag{3.11}$$

Pdf of log transformed x_L by mapping $p_{xL}(x_L)$ to $p_{\bar{x}L}(\bar{x}_L)$

$$p_{\bar{x}L}(\overline{x}_L) = \frac{1}{2\pi}\exp(\overline{x_L})\int_{-\infty}^{\infty}\phi^L(\frac{t}{L})\exp(-je^{\overline{x_L}}t)dt \quad (3.12)$$

Here $\bar{x}_L = \ln(x_L)$

3.3.2 The Approximation Method Using the Edgeworth Expansion

In this section, we used the Edgeworth expansion to characterize the multi-look speckle in the amplitude format [6], and provide a straightforward but approximate analytical expression for $p_{fL}(f_L)$ as a product of a Gaussian pdf and Hermite polynomials weighted by cumulants. We will finally derive p $\overline{f}$ ($\overline{f_L}$) from the approximate $p_{fL}(f_L)$.

$$p_{f_L}(f_L) = \frac{1}{\sqrt{2\pi}\sigma_L}\exp(-\frac{(f_L-\mu_L)^2}{2\sigma_L^2})(1+\frac{c_{3,L}}{3!\sigma_L^3}H_3(\frac{f_L-\mu_L}{\sigma_L})+\frac{c_{4,L}}{4!\sigma_L^4}H_4(\frac{f_L-\mu_L}{\sigma_L})+\frac{10c^2{}_{3,L}}{6!\sigma_L^6}H_6(\frac{f_L-\mu_L}{\sigma_L})) \quad (3.13)$$

where $f_L \geq 0$, $\mu_L and \sigma_L$ are computed directly from data set

For log transformed speckle,

$$p_{\bar{f}_L}(\bar{f}_L) = \frac{1}{\sqrt{2\pi}\sigma_L}\exp(\bar{f}_L - \frac{(e^{\bar{f}_L}-\mu_L)^2}{2\sigma_L^3})(1+\frac{c_{3,L}}{3!\sigma_L^3}H_3(\frac{e^{\bar{f}_L}-\mu_L}{\sigma_L})+\frac{c_{4,L}}{4!\sigma_L^4}H_4(\frac{e^{\bar{f}_L}-\mu_L}{\sigma_L})+\frac{10c^2{}_{3,L}}{6!\sigma_L^6}H_6(\frac{e^{\bar{f}_L}-\mu_L}{\sigma_L})) \quad (3.14)$$

Here $H_n(x)$ Chebyshev–Hermite polynomial of degree n. this can be calculated by putting value of x in the equation given below.

$$\left(\frac{d^n}{dx^n}\right).e^{-\frac{x^2}{2}} = (-1)^n.H_n(x).e^{-\frac{x^2}{2}} \quad (3.15)$$

$$c_{3,1} = M_{3,1} - 3M_{2,1}M_{1,1} + 3M_{1,1}^{3} \tag{3.16}$$

$$c_{4,1} = M_{4,1} - 4M_{3,1}M_{1,1} - 3M_{2,1}^{2} + 12M_{2,1}M_{1,1}^{2} - 6M_{1,1}^{6} \tag{3.17}$$

$$M_{k,1} = (\frac{4}{\pi})^{\frac{k}{2}}\Gamma(1+\frac{k}{2}) \tag{3.18}$$

3.3.1 Method of moments:

We used this method of moments (MoM) estimation technique to find the unknown parameter of Weibull distribution.

$$f(x;b,c) = \frac{c}{b^{c}}.x^{c-1}\exp(-(\frac{x}{b})^{c}) \qquad ; \quad x \geq 0 \tag{3.19}$$

Where, c = shape parameter and

b = scale parameter

First order mean of x can be denoted as

$$E[x] = b.\Gamma(1+\frac{1}{c}) \tag{3.20}$$

Second order mean of x can be denoted as

$$E[x^{2}] = b^{2}.\Gamma(1+\frac{2}{c}) \tag{3.21}$$

Variance of x can be denoted as

$$\text{var}[x] = b^{2}[\Gamma(1+\frac{2}{c}) - (\Gamma(1+\frac{1}{c}))^{2}] \tag{3.22}$$

So coefficient of variation ‘CV’ can be calculated as

CV = standard deviation / mean

$$CV = \frac{\sqrt{\Gamma(1+\frac{2}{c}) - \Gamma^2(1+\frac{1}{c})}}{\Gamma(1+\frac{1}{c})} \tag{3.23}$$

For different values of ‘c’ we form a table of ‘CV’, in order to estimate ‘b’, ‘c’ we need to calculate CV of the data given $(CV)_d$. Now we compare $(CV)_d$ and CV to estimate shape parameter $\hat{c}$.

Scale parameter can be estimated as

$$\hat{b} = \frac{m_1}{[\Gamma(1+ {}^{1}\!/_{\hat{c}})]} \tag{3.24}$$

Here $m_1 = \frac{1}{n}\sum_{i=1}^{n}[x_i]$

CHAPTER-4

Experimental Results

4.1 Data description:

The SAR data set used in this research work have been obtained by Sandia National Laboratory with 'MINISAR' platform on August 17, 2005. This sensor operates in Ku-band with the central frequency of 16.8 GHz, with resolution of approximately 10×10 cm. Major characteristics of this SAR system are given in the table below.

Table 4. 1 : Miniature Synthetic Aperture Radar (Mini-SAR) Characteristics

Data collector	Sandia National Lab
Date of acquisition	17/08/2005
Platform	MINISAR
Range resolution	0.1016 m
Azimuth range resolution	0.1016 m
Range pixel size	0.0847 m
Azimuth pixel size	0.0847 m
Central frequency	16.8 GHz
Bytes Per Pixel	4
Range count	1638
Azimuth count	2510
No. of looks	1

There are 20 images in the data set, and we have selected six different SAR data files (based on the shape of SAR histogram and degree of heterogeneity of SAR image). These data files used for experimental analysis are denoted as "EubGatEnt", "NatGuaArm", "StatMis", "TijArrGlf", "WyoGatEnt", "C130Osp" Selection of data files is entirely based on visual inspection. Here, coefficient of variation, CV (the ratio of standard deviation to mean) is used as metric for degree of heterogeneity. Larger the CV value, more is the degree of heterogeneity of the SAR image.

4.2. pdf Estimation Results

In order to analyze statistics of speckle, comparison of histogram of speckle and the estimated pdfs is made qualitatively (through visual comparison), and quantitatively (by calculating Kullback-Leibler distance). This KL distance between data histogram (h_d) and estimated pdf (h_e) is given by,

$$D_{KL}(h_d \| h_e) = \sum_r \ln\left(\frac{h_d(r)}{h_e(r)}\right) h_d(r) \tag{4.1}$$

Smaller the DKL value, better is the goodness-of-fit of estimated pdf to the data histogram.

Table 4. 2:Values of Coefficient of variation, CV and KL Distance, DKL obtained using Edgeworth Expansion and Weibull distribution

Image	CV	D_{KL}	
		Edgeworth	**weibull**
C130Osp	0.6204	0.0287	0.0354
NatGuaArm	0.5444	0.0153	0.0141
WyoGatEnt	0.5059	0.0100	0.0031
StatDisp	0.4898	0.0126	0.0030
EubGatEnt	0.4482	0.0120	0.005
SatMis	0.4356	0.0115	0.0025

.We have used mean, Lee, Kuan, Frost filters to obtain speckle from SAR data set, out of these three filter frost filter has given best result of speckle.

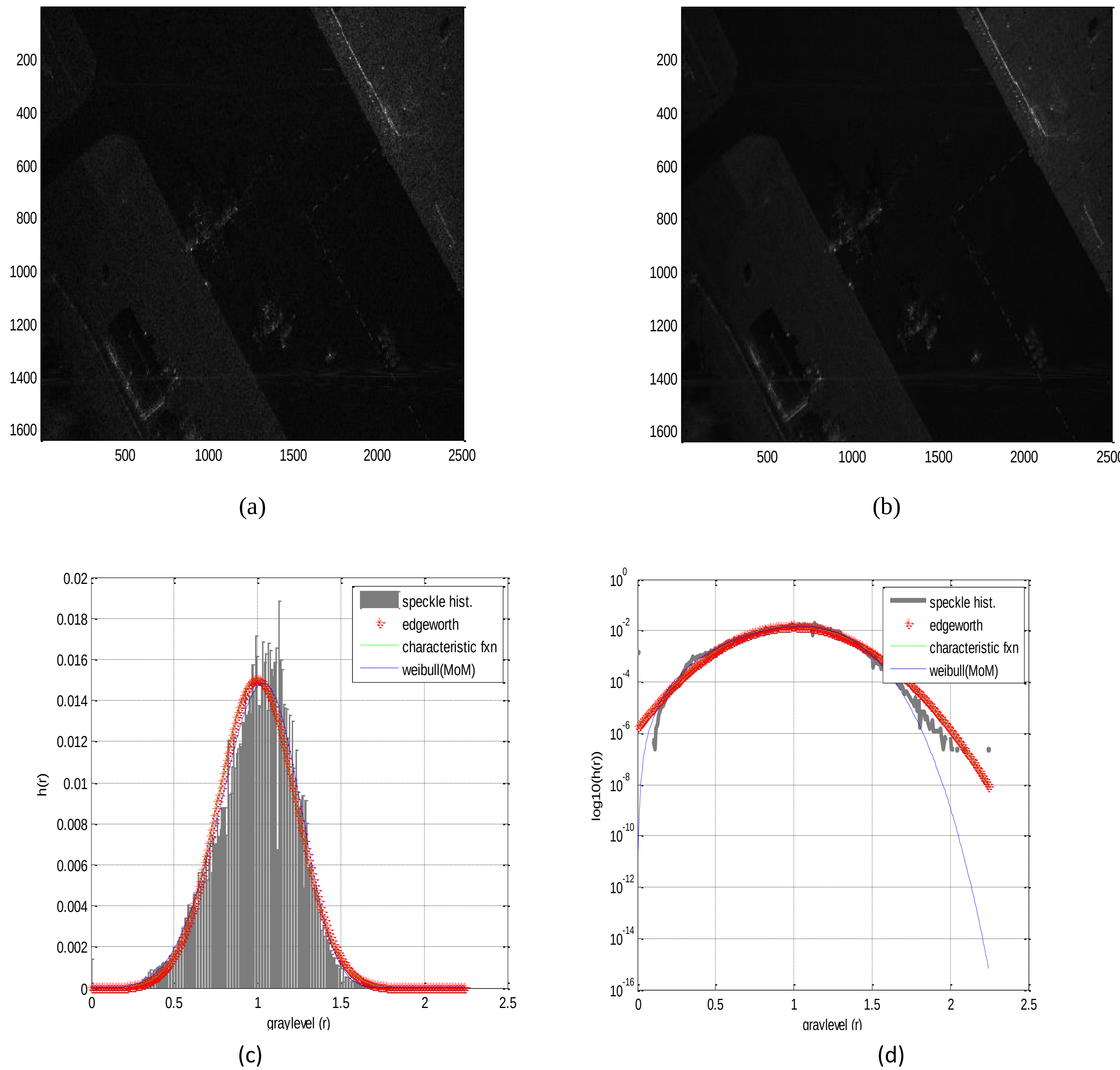


Figure 4. 1 - (a) Original image “C130Osp”, (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively

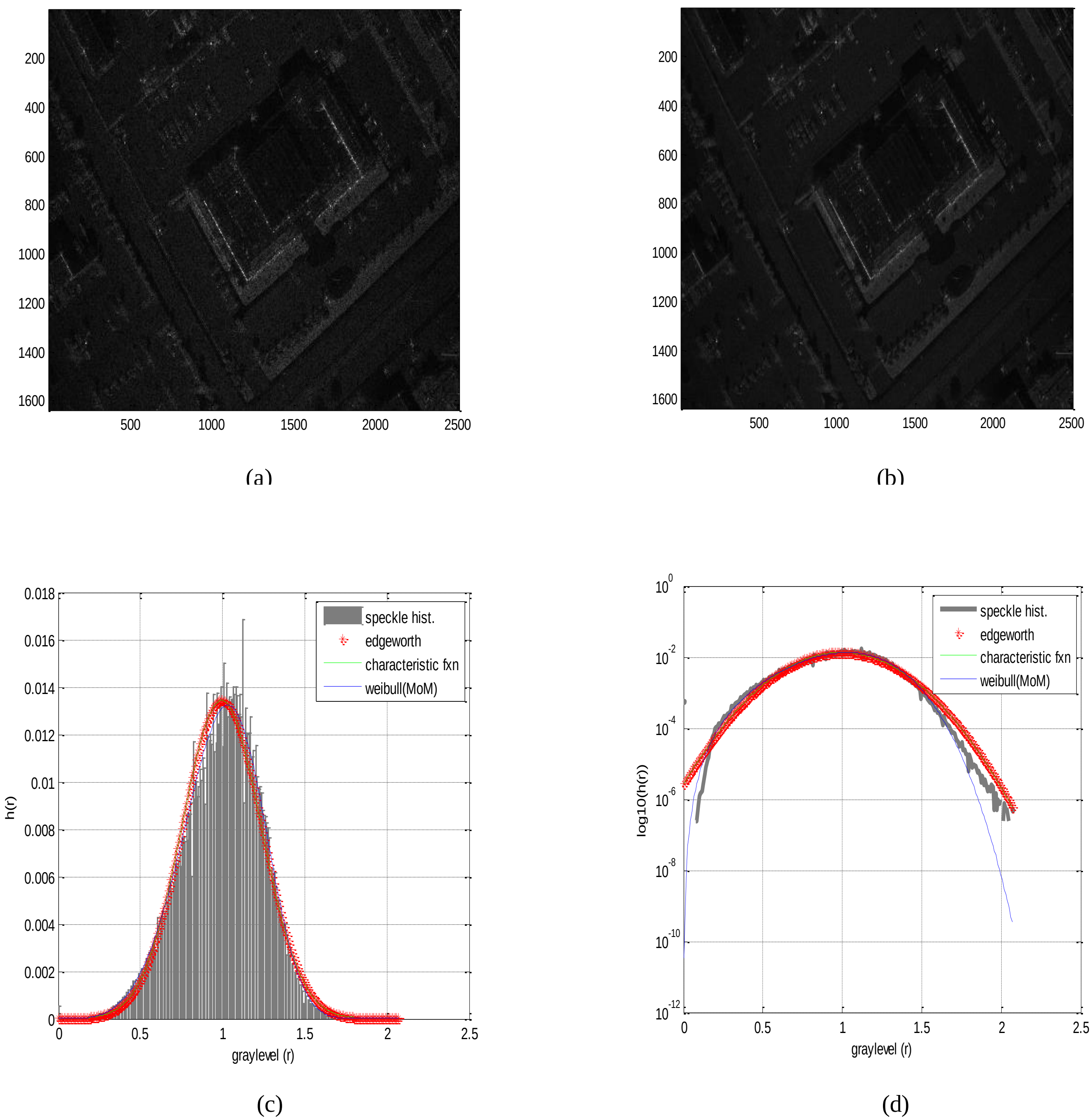
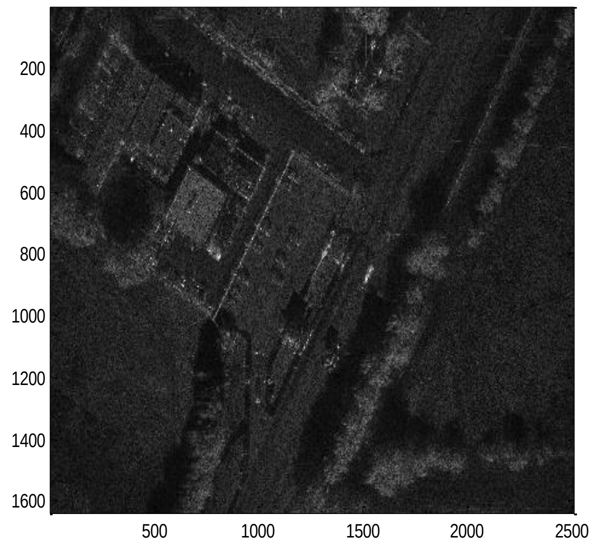
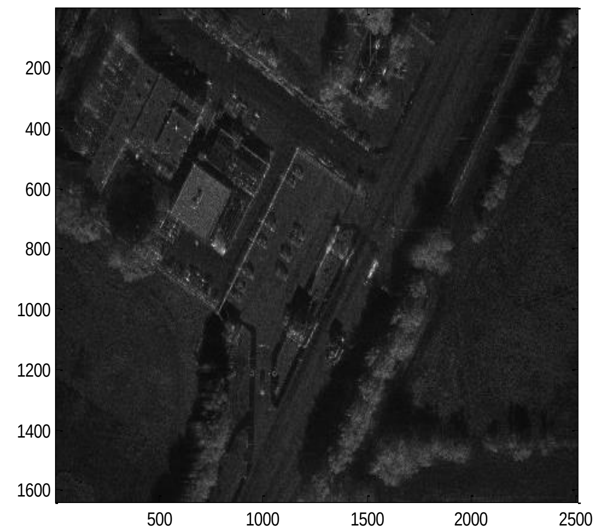


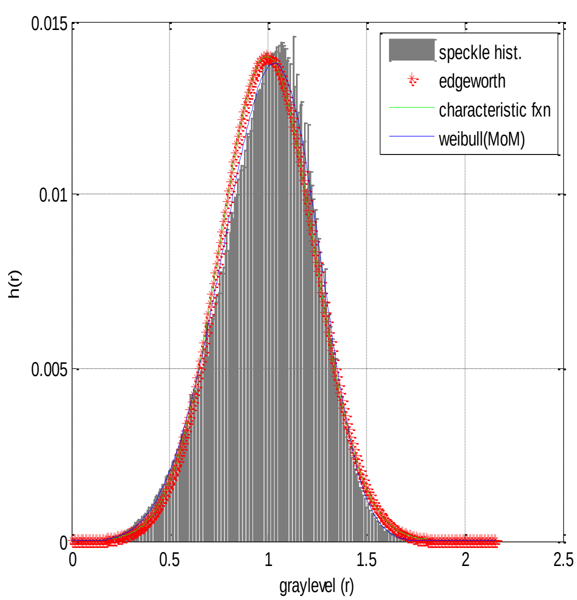
Figure 4. 2 - (a) Original image “NatGuaArm”, (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively



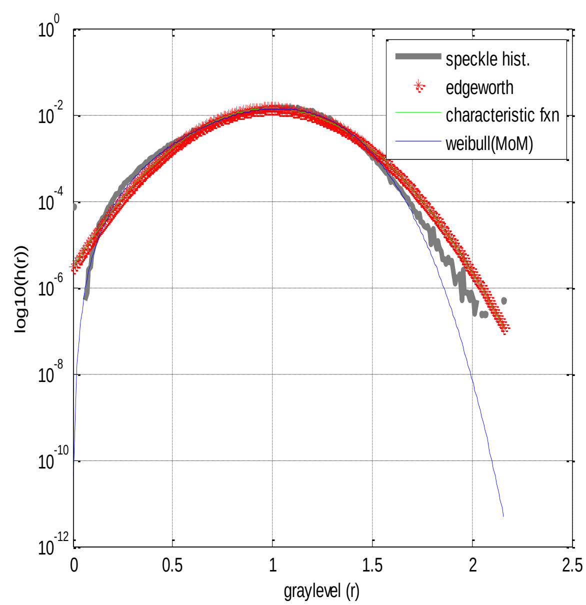
(a)



(b)



(c)



(d)

Figure 4. 3 -(a) Original image “WyoGatEnt”, (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively

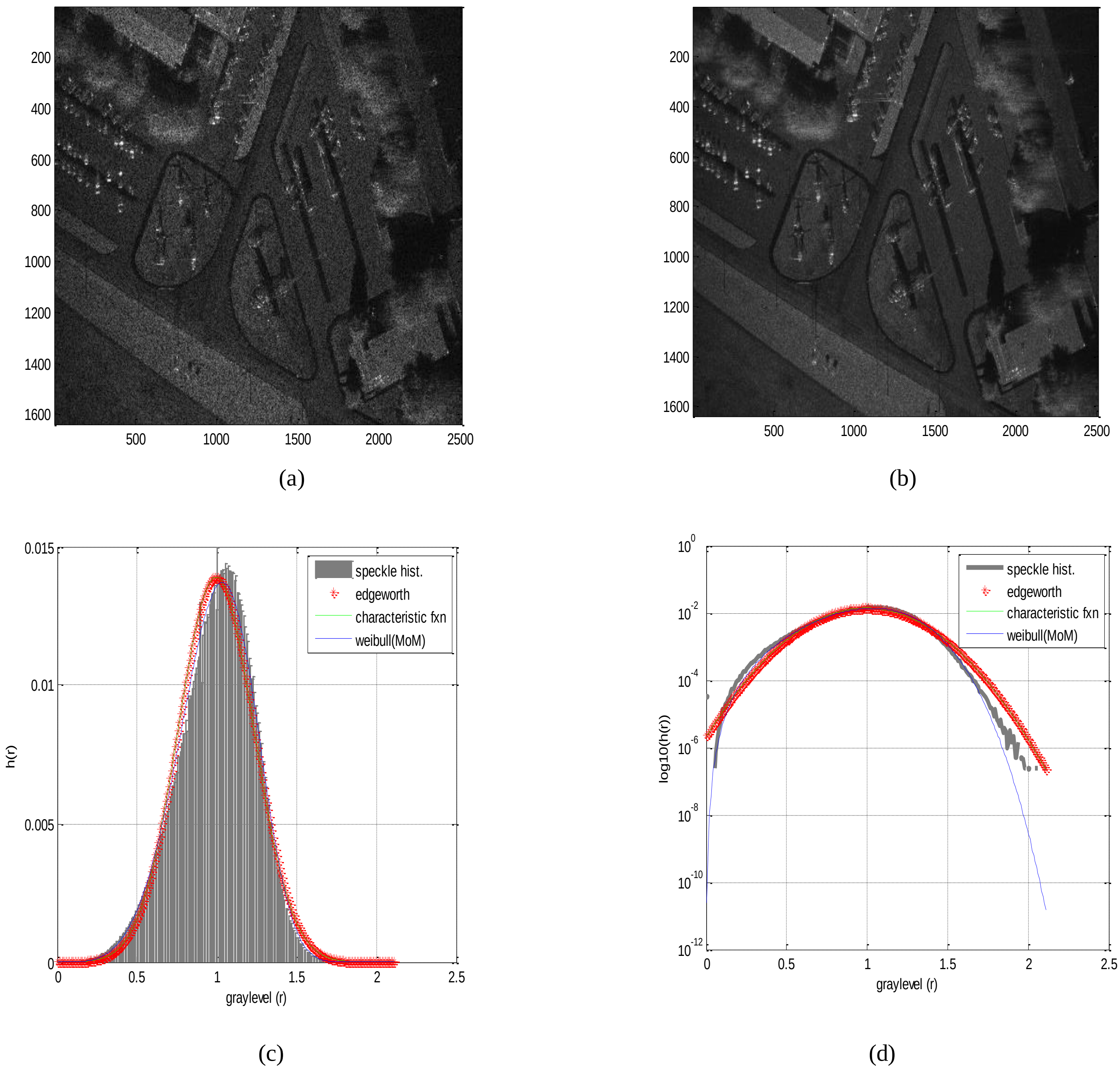
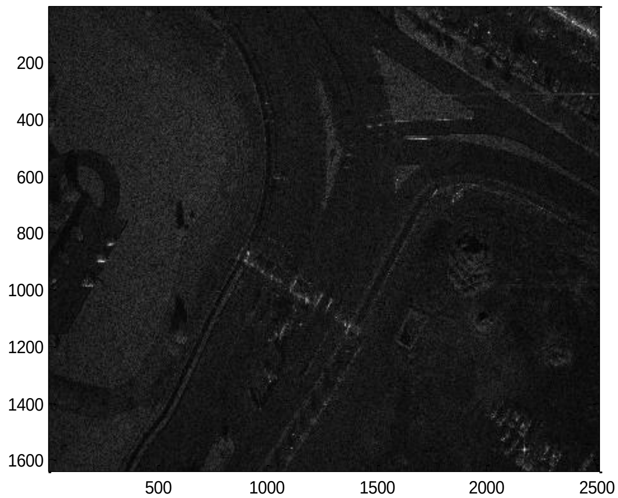
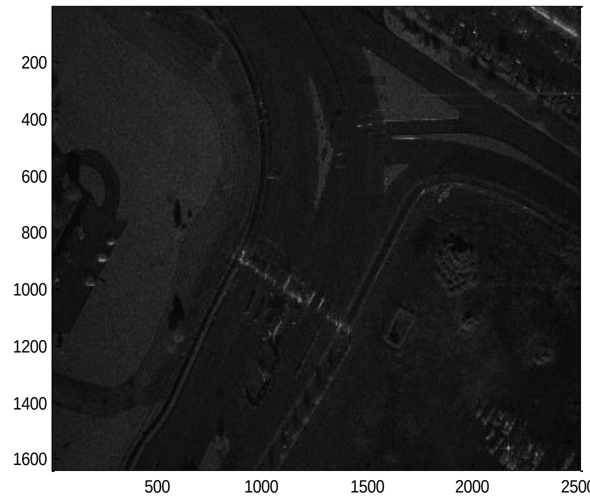


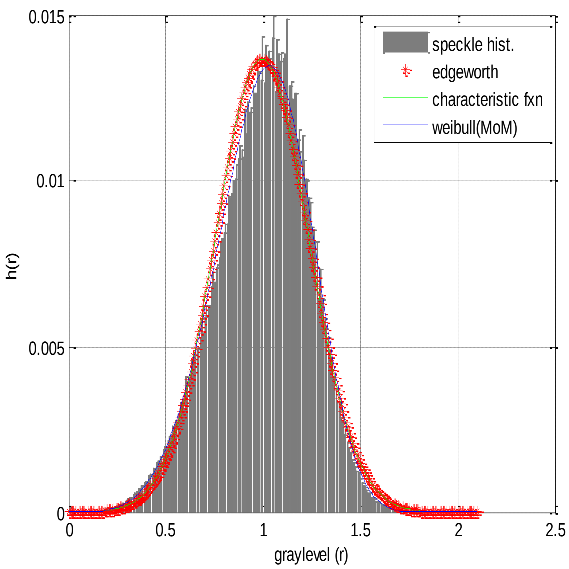
Figure 4. 4 -(a) Original image “StatDisp”, (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively



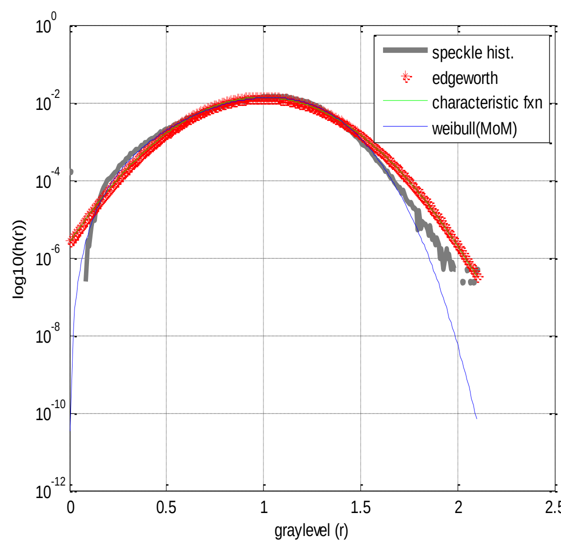
(a)



(b)



(c)



(d)

Figure 4. 5 -(a) Original image "EubGatEnt", (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively

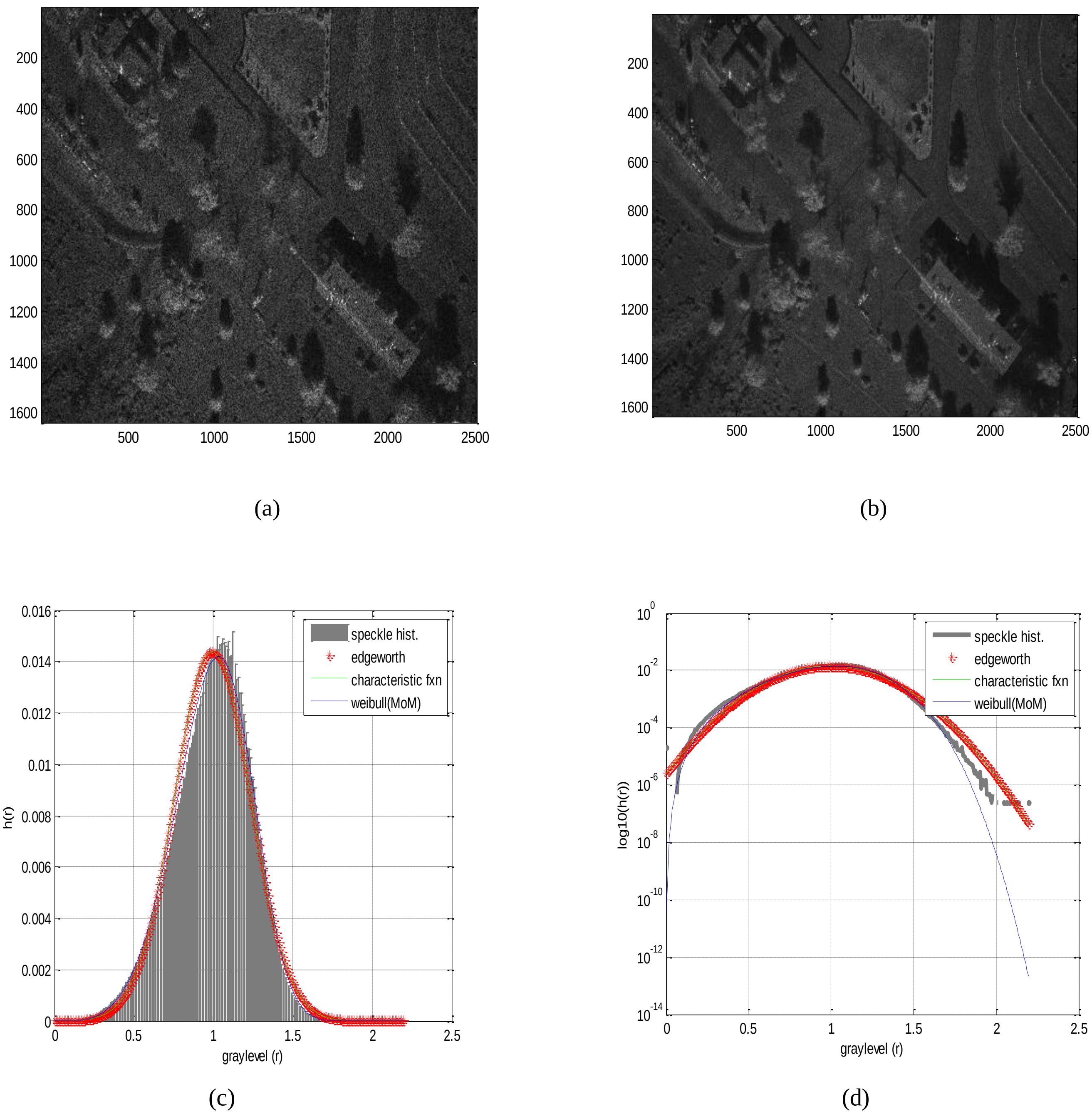
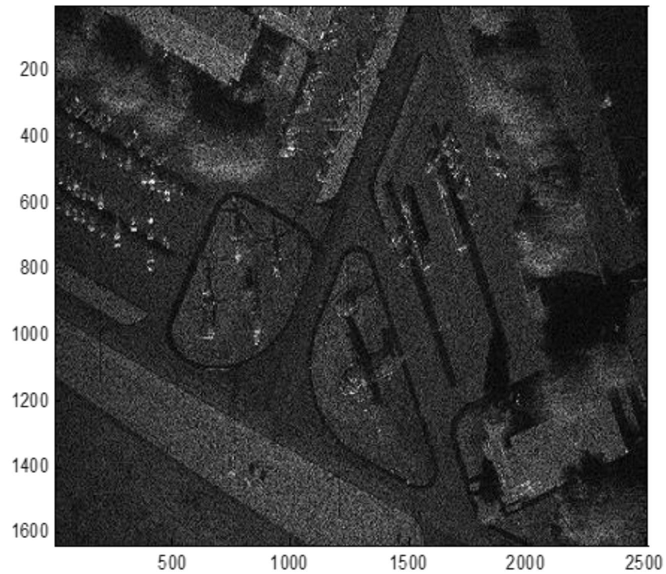
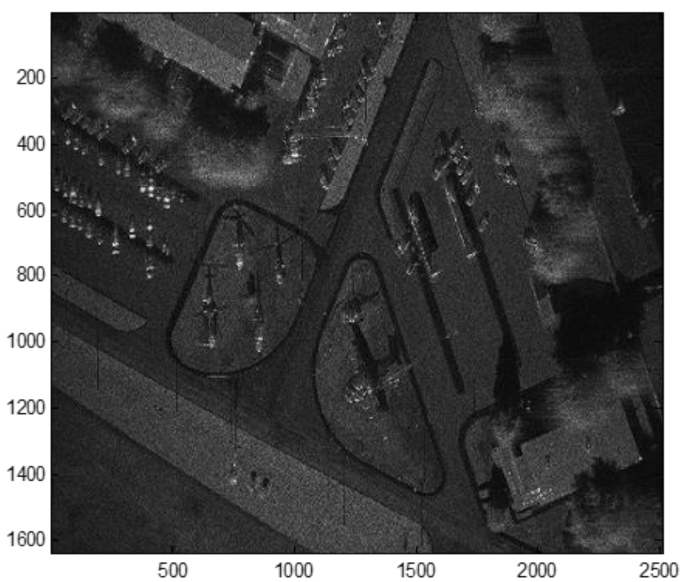


Figure 4. 6 - (a) Original image “StatMis”, (b) Filtered image using frost filter, (c) – (d) Comparison of speckle histogram and estimated pdf in linear and semilog scale respectively

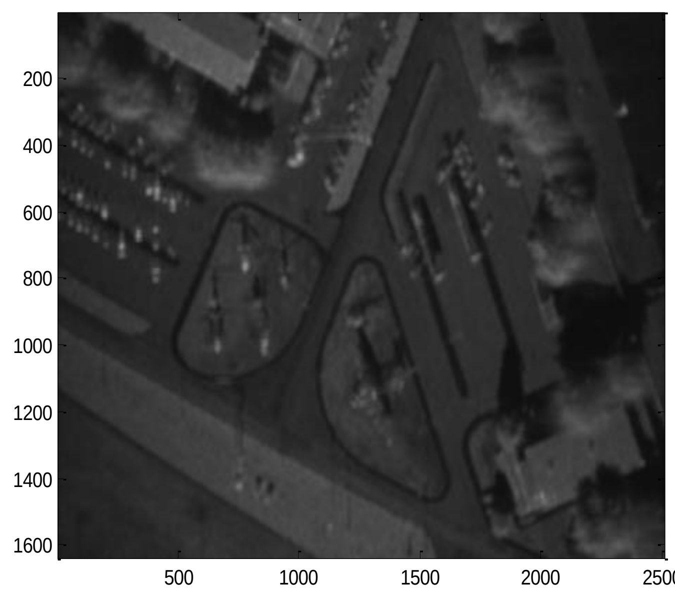
Effect of changing window size:



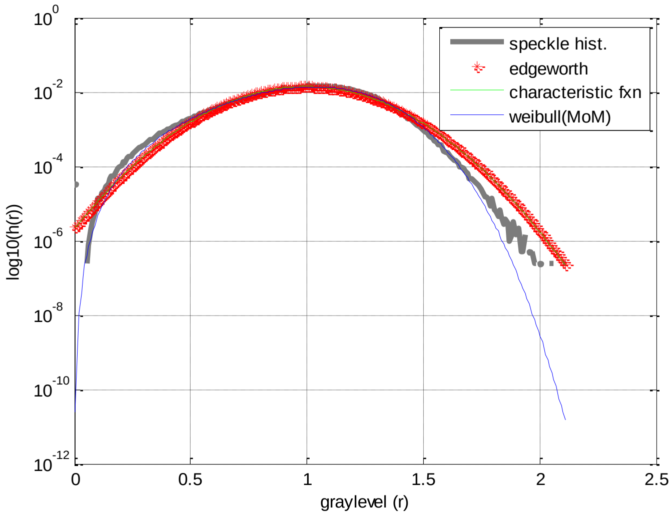
(a) Original image "StatDisp"



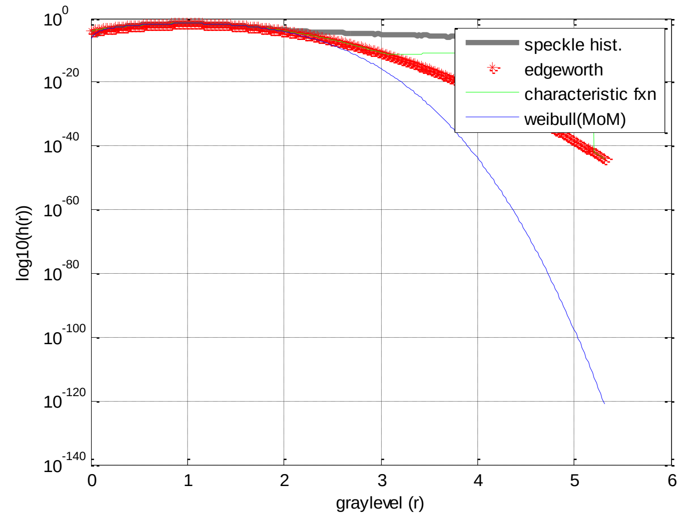
(b) Filtered image (window size 3×3)



(c) Filtered image (Window 21×21)



Window size 3×3



Window size 21×21

Table 4. 3 Effect of window size

Window size	**3×3**	**21×21**
DKL(Edgeworth)	0.0126	0.0136
DKL(Weibull)	0.0030	0.0298

CHAPTER-5

Conclusion and Future Scope

5.1 Conclusion:

1. By seeing linear and semilog scaled graph and comparison table it is proved that as the degree of heterogeneity (value of CV) decrease KL distance also decreases, and got more goodness-of-fit of speckle data histogram and estimated pdf.
2. By increasing window size of filter KL distance increases, and also got blurred image after filtration.

5.2 Scope for future work:

This research can be extended by developing advanced texture preserving filters to remove maximum speckle part from the raw SAR data.

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